Simple Normalization of Multi-temporal Thermal IR Data and Applied Research on the Monitoring of Typical Coal Fires in Northern China

Bo Yang, Yunhao Chen, Jing Li, Adou Gong
Key Laboratory of Environment Change and Natural Disaster, Ministry of Education of China
College of Resources Science & Technology, Beijing Normal University
Beijing, 100875, China
yb@ires.cn

Claudia Kuenzer, Jianzhong Zhang
German Aerospace Center (DLR)
German Remote Sensing Data Center (DFD)
Oberpfaffenhofen D-82234 Wessling, Germany

Abstract—**China is one of the countries with vast coal resources in the world. However. Many coalmines in China seriously endangered by coal fires. Investigations showed that there were 104 coal fires in Northern China. About 100-200 million tons of coal is being lost because of coal fires each year, Account for one fifth of national annual coal production. More seriously, coal fire also endangered human being and property security, induced disastrous ecological damage and environmental pollution. Though the problem of coal fire is long standing and not only limited in China, little has been done around the world for regular monitoring of these fires based on remotely sensed data. Some researchers used daytime thermal infrared (TIR) images from Landsat TM or ETM+ band 6 to monitor coal fires. Nevertheless, the combined impacts such as solar radiation, topographic shadowing, cover of vegetation, emissivity and different thermal inertia of ground objects result in the different background temperatures in different coal fires, and also lead to the thermal anomalies extracted out from multi-temporal thermal IR images lack of comparability. The intensity and extending range of thermal anomalies change frequently. It is a big puzzle for us to process continuous monitoring for coal fires. As a result, this research took different surface environmental parameters into account, and extracted out thermal anomalies based on the normalization of multi-temporal thermal IR images.**

Keywords-multi-temporal, thermal infrared (TIR), remote sensing, normalization, coal fire, monitoring, northern China ATCOR-3

I. INTRODUCTION

China is one of the countries abundant in coal resources around the world. But it is estimated that about 100-200 million tons of coal resources annually were burnt out for coal fires. Coal fire not only brings about severe waste of natural resources but also poses some negative impacts to ecological environment, and sustainable development as well.

Some researchers monitoring coal fires by use of daytime thermal infrared images from Landsat TM band 6 or ETM+ band 6[1-5]. However, on the daytime thermal IR images, the combined influence such as sensor calibration trends, different atmospheric conditions, variations in the solar illumination angles, cover of vegetation, emissivity and different thermal inertia of ground objects result in the different background temperatures in different thermal IR images, and also lead to those thermal anomalies individually extracted out from multi-temporal thermal IR images lack of comparability. As a result, it is widely recognized that a set of remotely sensed thermal IR images must be normalized before being used in a monitoring study. The approaches described before fall into two major categories: absolute normalization and relative normalization (Dave (1972)[6], Kaufman (1988)[7], F.G. Hall et al. (1991)[8], Rahman et al (1994)[9], Richter (1990,1996)[10,11], Jensen (1996)[12], T.A.Warner and X.Chen (1999)[13], Y. Du et al. (2002)[14], E.A.McGovern et al. (2002)[15], J. Feng et al. (2003)[16], M. J.Canty et al.(2004)[17].and T. Nielsen (2005)[18].

Most of aforementioned normalization approaches only deal with optical and near infrared data but not for TIR images. This research tries to normalize multi-temporal daytime TIR images through radiometric correction firstly, and then make full use of high resolution DEM to do some atmospheric correction in ATCOR-3 to decrease the topographic influence. Finally extracted out coal fire related thermal anomalies from multi-temporal TIR images and accomplished the dynamic monitoring for coal fires in typical coalfields in Northern China.

II. STUDY AREA

Wuda coalfield belongs to Inner Mongolia Autonomous Region in Northwestern China. It is located on the western side of the Yellow River, north of the Helanshan mountain range. The geographic location is extending latitudinally from 39º27′ N to 39º34′ N and longitudinally from 106º34′ E to 106º38′ E. The small study area -- Wuda syncline -- approximately extends from North to South for about 13 km and includes an

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14. ABSTRACT

15. SUBJECT TERMS

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area of about 200 km2, with Suhaitu coalmine in the North, Wuhushan coalmine in the South and Huangbaici coalmine at the center (Fig 1). Land elevations in this region vary from 1122 to 1350 meters above sea level.
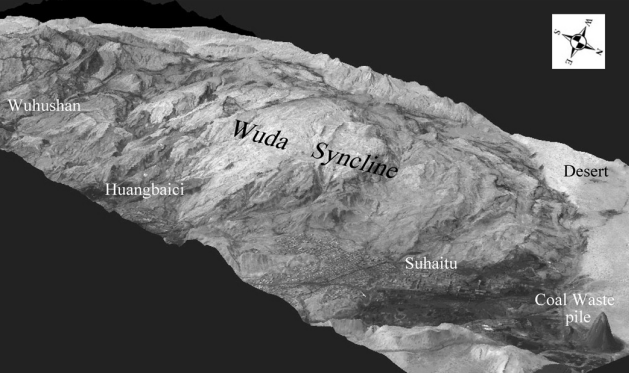

Figure 1.   3-D relief map of research area

III.   MATERIAL AND PRE-PROCESSING

The data set includes multi-temporal Landsat-7 ETM+ band6 TIR images over study area, high spatial resolution Quickbird images (pixel size 60cm), and also a high precise DEM generated from topographical map with a scale of 1:5000 (TABLE Ⅰ).

Two Landsat-7 ETM+ images acquired on August 12, 1999 and September 22, 2002.The full scene location reference was P129R33 on the Landsat World-wide Reference System (WRS-2). There were no clouds visible in both images.

The accuracy of geometric rectification can have a direct bearing on the accuracy of the subsequent radiometric normalization. The 2002 daytime image was selected as the master image because we simultaneously acquired in-situ GCPs, which can also be used for the orthorectification of 2003 Quickbird image. The1999 daytime image was registered to the master image by an image-to-image registration. This proved to be relatively easy because of the similar resolution, and the corresponding GCPs were easy to be found out during the process of geometric correction and projective transformation subsequently.

A digital elevation model (DEM) with a pixel spacing of 1 m was created by digitizing a 1:5000 topographic map to correct the influence of topography on Landsat ETM+ radiance. The DEM was registered to Landsat ETM+ data and the RMS registration error was less than 10 m.

TABLE I.   DATA SET OF THIS RESEARCH

Data type	Scene	Acquisition time	Zenith/ degree	Azimuth/ degree
Landsat ETM+	129/33	12, August 1999	31.4	132.73
Landsat ETM+	129/33	21, September 2002	43.0	147.21
Quickbird		5, October 2003		
DEM		Scale 1:5000		

IV.   METHODS

The coal fire monitoring based on the simple normalization of multi-temporal TIR images includes several steps as follows:

A.   Radiometric calibration

Firstly, radiometric calibration towards multi-temporal TIR images was made by input calibration parameters that can be seen in metadata into ENVI4.0.

B.   Atmospheric correction

According to the DEM surface slope, aspect, and shadowing analyses, do some atmospheric correction and finally got a surface solar radiation intensity (illumination) map through ATCOR-3.

C.   Simple normalization

Use different solar illumination maps to rectify multi-temporal daytime TIR images of Landsat ETM+ band6. Usually, we use multi-temporal raw TIR images to subtract corresponding solar illumination maps obtained from the treatment before, and to decrease the impact of solar radiation. That is to say:

$$P - I = N \qquad (1)$$

where P is the raw TIR image, I is the illumination map which was obtained by atmospheric correction in ATCOR-3, and N is simply normalized TIR image.

D.   Extract thermal anomalies

On the basis of normalized multi-temporal TIR images. Via a thresholding method, density slicing the TIR images and the extraction of thermal anomalies can be achieved. It is the ordinary method used in the extraction of thermal anomaly.

In the future, an algorithm developed at the German partner institute DFD will be available for automated hot spot detection from the images.

E.   Supervised classification and mask treatment

By use of supervised classification towards the multi-spectral Quickbird images. We obtained the classification image of typical ground objects such as sandstone, shale and most important of all, the coal outcrops and coal waste piles (Figure 5 left).

Some mask treatments were done subsequently to eliminate those thermal anomalies not related to coal fires.

F.   Coal fire monitoring

Finally, we extracted out thermal anomalies from multi-temporal TIR images, and then can do some primary monitoring for coal fires in Wuda area.

These methods were taken into the effects to monitoring coal fires in typical coalfield in Northern China and achieved good results that to be delineated later.

V. RESULTS

After the radiometric calibration, the contrast of the TIR images can improve a lot (Figure 2). It is meaningful to the following steps

(a) to (e) in Figure 3 and Figure 4 are all needed parameters for atmospheric correction by use of ATCOR-3 in PCI Geomatica 9.0, and (f) is the result TIR map after this treatment, the contrast is quite different with Figure 2 in comparison.
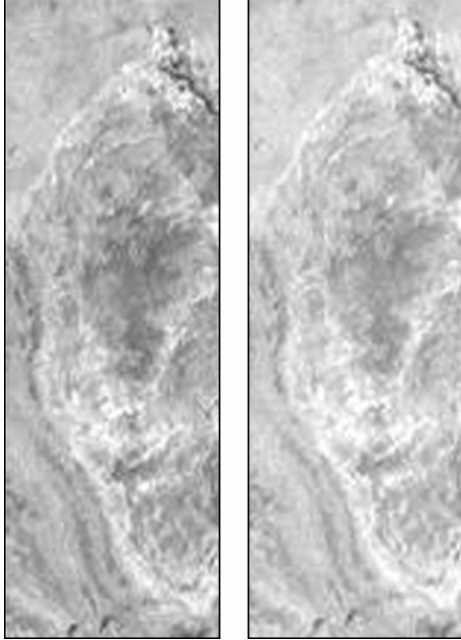

Figure 2. Right: TIR band before radiometric calibration, left:TIR band after radiometric calibration .
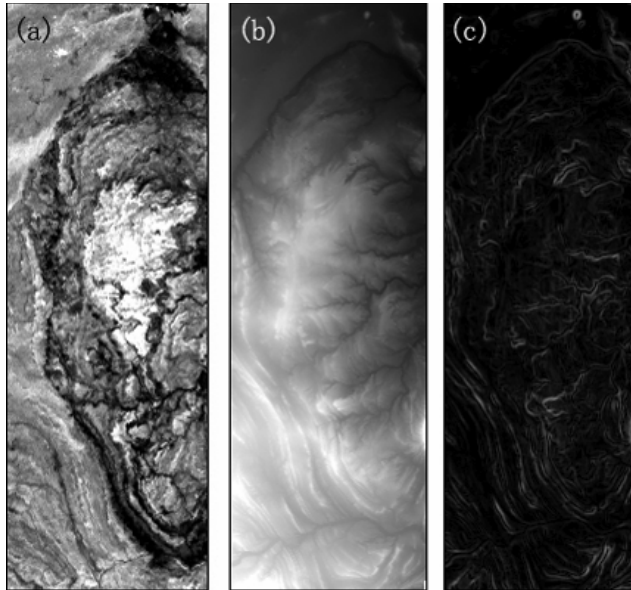

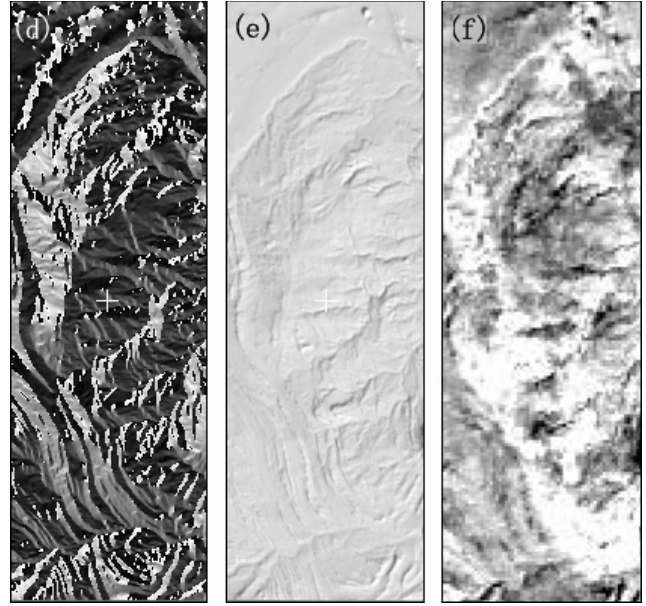Figure 3. Image input parameters for atmospheric correction in ATCOR-3

Figure 4. Image input parameters for atmospheric correction in ATCOR-3

(a) Image bands, (b) DEM, (c) slope, (d) aspect, (e) shadowing of 12, August 1999,sun azimuth=132.73, solar zenith=31.4 (f) the result map after atmospheric correction in ATCOR-3.

In Figure 5, the left one is a distributing map of coal and coal waste piles after supervised classification on Quickbird images, and then, some mask treatment to exclude the thermal anomalies not coal fire related can be done, the middle image are thermal anomalies extracted out from 1999 ETM+ band 6, and the right one are thermal anomalies extracted out from.2002 ETM+ band 6.
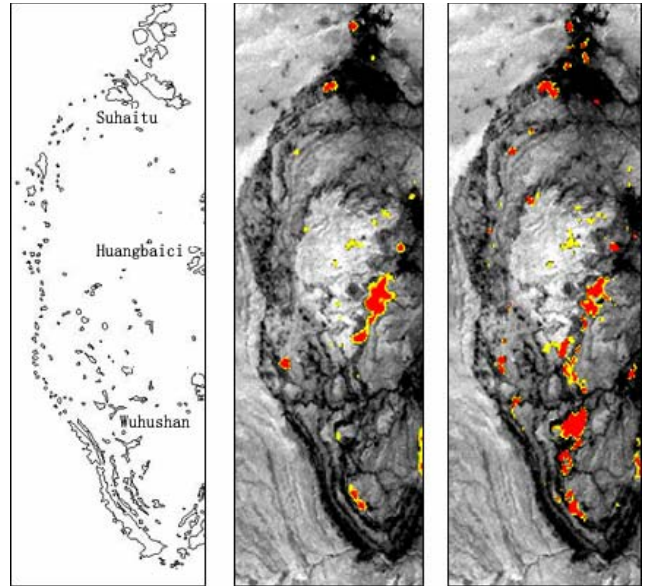

Figure 5. Thermal anomalies extracted out from simple nomalized multi-temporal TIR images (detail description see upper paragraph)

Red colors in the Figure 5 represent areas of high temperature thermal anomalies, mostly corresponding to underground coal fires, yellow colors indicate medium temperature areas. The comparison of thermal anomalies extracted separately from 1999 and 2002 images proved that the coal fire area in Wuda enlarged greatly in those years.

VI. DISCUSSION

The normalization of multi-temporal thermal infrared data is very important to do some dynamic monitoring towards those surface temperatures related work. But there still no very good methods yet to solve this problem. The simple normalization method used in this research tries to reduce the solar radiance and topographic effects as many researchers had tried before. Though achieved a relatively good result. The problem still exist and more work need to be done in the future. Such as how to compare the thermal anomalies extracted out from daytime and nighttime TIR data separately? How to compare the change tendency between thermal anomalies extracted out in different seasons with various background temperatures, etc.

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